



FACTORS AFFECTING HMA PERMEABILITY

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In HMA construction, it is important that the mix be adequately compacted in-place so that initial permeability is low. Low in-place density allows for water and air to penetrate into HMA pavements. This condition leads to an increased potential for damage such as stripping, raveling, cracking, and excessive oxidation of the asphalt binder. In general, the use and type of compaction equipment and practices used during construction can affect the final in-place air voids – and the use of a coarse-graded mix can increase the potential of obtaining a more permeable pavement. Since a limited number of coarse-graded $\frac{3}{4}$ inch HMA pavements in Washington have exhibited poor permeability characteristics (moisture weeping, freezing and excessive aging of the binder), this Tech Note was assembled to share national research results.



Image 1. Weeping of permeable pavement (University of Arkansas).

Research has identified some common factors that affect HMA permeability and include nominal maximum aggregate size (NMAS), lift thickness, and compaction¹.

Also, a comparison of absorption and permeability between field cores and gyratory samples is presented since findings have shown that these factors are interrelated. Prior to the introduction of Superpave, Washington State used the Hveem design system, which lent itself to fine-graded mixes that passed near or above the maximum density line (MDL) and were rarely permeable. Fine-graded mixes contain gradations that pass above the MDL at the No. 8 sieve. Coarse-graded mixes have gradations that pass below the MDL at the No. 8 sieve. Figure 1 illustrates a generic difference between coarse- and fine-graded mixes using a 0.45 power chart.

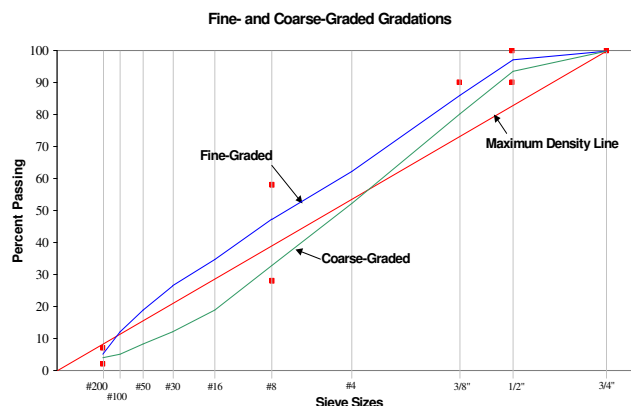


Figure 1. Comparison of coarse- and fine-graded mixes.

NMAS and Gradation

Research has shown that fine-graded Superpave mixes are less permeable than coarse-graded mixes. Also, when comparing two fine-graded mixes, the one with the

¹ R. Mallick, L. Cooley, Jr., M. Teto, R. Bradbury, & D. Peabody, NCAT Report No. 2003-02, *An Evaluation of*

higher NMAS will typically be more permeable².

Typically, as the NMAS increases, the size of the individual air voids increase, and as the air void size increases, the permeability of the pavement increases as well³. As seen in Figure 2, the left image shows a fine-graded mix with the air void space being filled by smaller aggregate particles. The image on the right shows more void space created by the lack of fine aggregate particles (i.e. a coarse-graded mix).

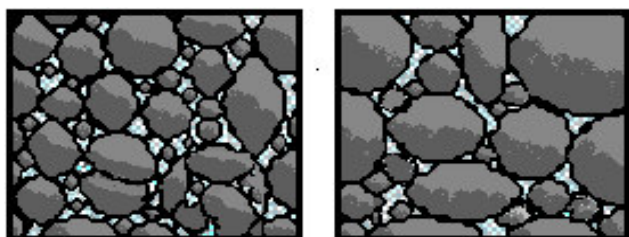


Figure 2. Fine-graded mix on the left and coarse-graded mix on the right.

In a study conducted by the National Center for Asphalt Technology¹ (NCAT), coarse-graded Superpave mixes with NMAS of $\frac{3}{8}$ inch (9.5 mm) and $\frac{1}{2}$ inch (12.5 mm) have similar permeability characteristics at given air void contents. Results have shown that when the in-place air void content exceeds 7.7 percent, these mixes become permeable. (Permeability is defined as field permeability greater than 100×10^{-5} cm/sec.) The $\frac{3}{4}$ inch (19.0 mm) mixes had significantly higher permeability values at the same air void content as the $\frac{3}{8}$ inch and $\frac{1}{2}$ inch mixes. Slight increases of in-place air voids above 5.5 percent greatly increased the permeability with $\frac{3}{4}$ inch mixes. The 1 inch (25.0 mm) mix displayed a permeability value about three times higher than $\frac{3}{4}$ inch mixes at the same air void content. The higher the NMAS, the larger the individual air voids and greater volume of interconnected air voids. Figure 3 shows best-fit curves for in-place air voids

versus permeability for the different NMAS mixes.

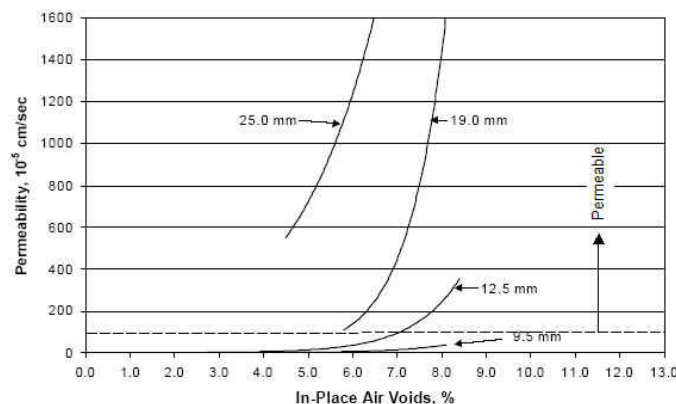


Figure 3. In-place air voids vs. permeability (NCAT).

Findings from research in Florida indicated that fine-graded mixes are relatively impermeable even at air voids significantly higher than 7 percent because of the minimal interconnected air voids².

While coarse-graded HMA pavements (even with a NMAS of $\frac{3}{8}$ or $\frac{1}{2}$ inch) can become excessively permeable to water with in-place air voids above 8 percent, there are times when a pavement can become permeable at lower air void contents. A $\frac{3}{4}$ inch mix (even when fine-graded) can become excessively permeable to water when in-place air voids are below 8 percent. Results from NCAT and Florida on $\frac{3}{4}$ inch mixes indicate that permeability can greatly increase with air void levels as low as 5.5 percent.

Design Lift Thickness

NCAT studies have also shown that the HMA lift thickness is related to permeability. Adequate lift thickness ensures proper aggregate alignment during compaction so that density and low permeability values can be achieved. Increasing the lift thickness may allow specified density levels to be achieved. A lift thickness-to-NMAS ratio ($t/NMAS$) minimum of 3.0 is most often recommended, but the use of a ' $t/NMAS$ ' ratio of 4.0 is preferred. NCAT findings showed that the lowest permeability values were also found with a ' $t/NMAS$ ' ratio of 4.0.

Within Washington State, the minimum lift thickness by type of mix is shown in Figure 4.

² B. Choubane, G. Page, J. Musselman, AAPT Vol. 67, 1998, *Investigation of Water Permeability of Coarse Graded Superpave Pavements*.

³ L. Cooley, Jr., B. Prowell, E. R. Brown, NCAT Report No. 2002-06, *Issues Pertaining to the Permeability Characteristics of Coarse-Graded Superpave Mixes*.

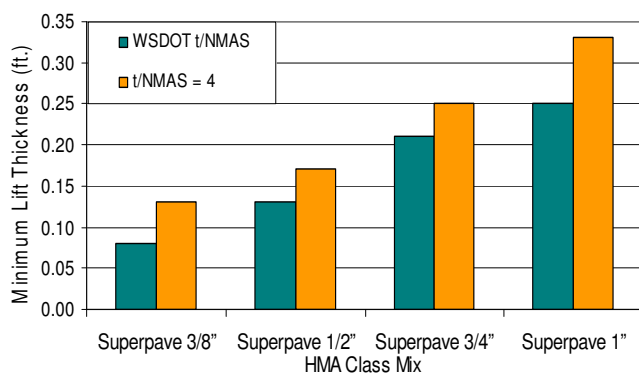


Figure 4. WSDOT minimum lift thickness.

The minimum lift thickness for mixes within WSDOT provide a lift thickness to NMAS ratio of 2.6 for the $\frac{3}{8}$ inch mix, 2.9 for the $\frac{1}{2}$ inch mix, 3.2 for the $\frac{3}{4}$ inch mix, and 3.0 for the 1 inch mix. Within WSDOT, the $\frac{3}{8}$ inch mix is generally used as a non-structural lift (i.e. prelevel). The predominant mix within WSDOT that is used as a surface course is the $\frac{1}{2}$ inch mix. It is primarily placed at a depth of 0.15 feet, which provides a t/NMAS ratio of 3.6. The $\frac{3}{4}$ inch mix has been used as a surface course, which is where WSDOT has seen minor permeability problems, but the current recommendation is to use this type of mix as a base or leveling course. The 1 inch mix is used as a base or leveling course. (Note: WSDOT typically does not see permeability issues with mixes when the state's minimum recommendation is used, except in some instances when larger NMAS mixes are used as a surface course).

Compaction

Testing by NCAT was conducted on 23 projects (Six $\frac{3}{8}$ inch NMAS, eight $\frac{1}{2}$ inch NMAS, six $\frac{3}{4}$ inch NMAS, and three 1 inch NMAS), all of which utilized gradations that passed below the MDL at the No. 8 sieve, with two exceptions: one $\frac{3}{8}$ inch mix was fine-graded and one was Stone Matrix Asphalt (SMA). NCAT has established a reasonable relationship in both the field and lab between pavement density and permeability, even though compacted laboratory and compacted field samples have different air-void distributions (known as density gradients). Table 1 shows NCAT recommended in-place air voids for various mix types.

Table 1. In-place density of various mixes.

NMAS	Average In-place Va (%)	Permeable at Va (%)	Density Required (%)
1" (25.0 mm)	4	4.4	95
3/4" (19.0 mm)	4 to 5	5.5	94
1/2" (12.5 mm)	~6	7.7	92
3/8" (9.5 mm)	Below 5	7.7	92

As is the case in Washington, most states utilize percent compaction for the acceptance of constructed pavements. These results show that density requirements could be changed dependent upon the type of mixture being produced. Examples may be to specify a compaction level of 94 percent for a $\frac{3}{4}$ inch mix with a coarse gradation or specify 92 percent compaction for a fine-graded $\frac{1}{2}$ inch mix.

Field Cores vs. Gyrotory Samples³

NCAT research also showed a good correlation between density and laboratory permeability for field samples and Superpave Gyrotory Compacted (SGC) samples. Comparisons were made between density and permeability for SGC samples and field cores. Results showed that the air void level at which a $\frac{3}{4}$ inch mix becomes impermeable differed by less than 0.5 percent, as seen in Figure 5. Findings indicate that SGC samples may be able to predict field permeability for all mixes, with the exception of the $\frac{3}{8}$ inch.

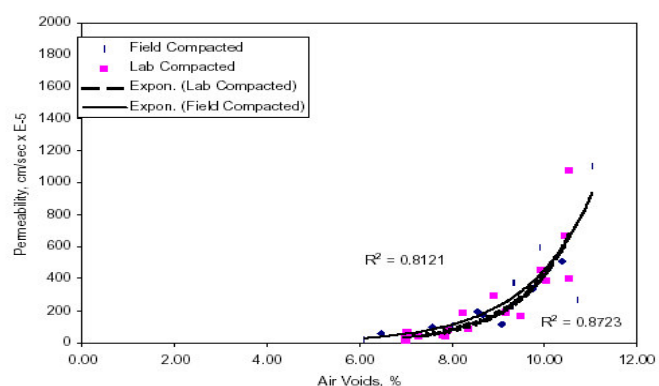


Figure 5. Density versus permeability of $\frac{3}{4}$ inch field cores and SGC samples (NCAT).

Water Absorption and Permeability

NCAT research has also shown a relationship between water absorption and permeability. There is an obvious relation between increasing air voids and increasing water

absorption, but according to AASHTO T-166, mixes with water absorptions greater than 2 percent lend themselves to interconnected air voids. Figure 6 shows the SGC and field sample air voids of the $\frac{3}{4}$ inch mixes in relation to the water absorption. This figure shows that air voids increase with water absorptions greater than 2.0 percent. Also note that 2.0 percent absorption corresponds with approximately 7.5 percent air voids.

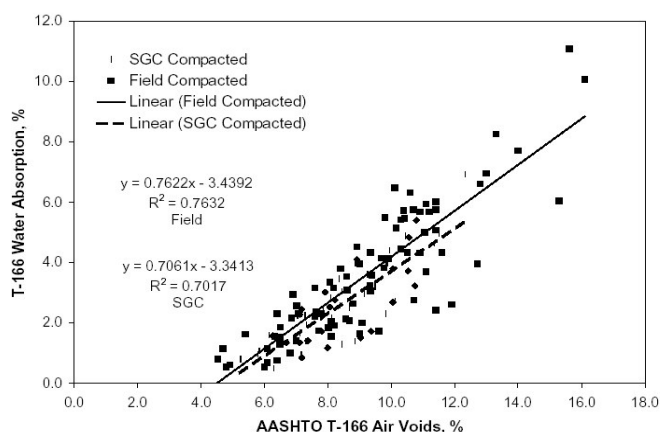


Figure 6. Air void and water absorption relationship (NCAT).

Further results show a relationship between water absorption and permeability. Permeability testing compared core samples of field, laboratory, and the SGC. A similar relationship exists between water absorption and permeability for differing conditions (Figure 7) of laboratory and field compacted samples.

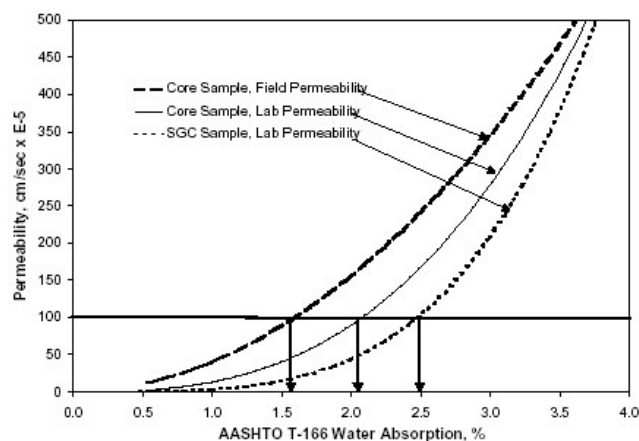


Figure 7. Water absorption versus permeability (NCAT).

These findings show that water absorption testing could be used during the design process to determine whether a submitted

design is prone to permeability. To determine whether the permeability of a mix is at an acceptable level for its application, the density and water absorption need to be calculated. From this data, the potential for field permeability can be estimated. Additional information could be obtained from these results and used to assist with field density requirements. Currently, there is not an AASHTO procedure or guideline for this type of application.

Conclusions

As the NMAS increases, pavement permeability increases and higher NMAS results in larger individual air voids creating a greater volume of interconnected air voids. NCAT determined that the lowest permeability was found with a $t/NMAS$ ratio of 4.0. Adequate lift thickness will help ensure proper aggregate alignment during compaction, so that density can be achieved and permeability avoided.

A reasonable relationship exists between pavement density and permeability, even though compacted laboratory and field samples have different air void distributions. SGC samples during design may be able to predict field permeability when measuring water absorption. In general, higher densities result in a more impermeable mix. Based on this information and findings related to water absorption and permeability, in-place density specifications could be modified depending upon the type of mixture being produced.

Avoiding excessive permeability is important to ensure pavement longevity. Mixes need to be designed and constructed to ensure permeability will not become a performance issue. WSDOT will continue to evaluate HMA pavements to ensure they perform as expected and that permeability is minimized.

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